Chapter 9

Vulnerability of the New York City Metropolitan Area to Coastal Hazards, Including Sea-Level Rise: Inferences for Urban Coastal Risk Management and Adaptation Policies

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Introduction

Many of the world's largest cities are situated at coasts and in estuaries at or near sea level. Major coastal urban centers have long been vulnerable to natural hazards, such as storm surges, shoreline erosion, or even the occasional destructive tsunami (Nicholls, 1995). By the end of this century, increased rates of sea-level rise (SLR) could cause permanent inundation of portions of low-lying coastal cities, repeated flooding episodes, and more severe beach erosion (Houghton et al., 2001; McCarthy, Osvaldo, Canziana, Dokken, & White, 2001). The anticipated SLR will challenge coastal managers and decision makers to adapt to and mitigate these potentially adverse effects of climate warming in innovative and creative ways.

The vulnerability of the New York City metropolitan region to SLR was examined as part of the Metropolitan East Coast (MEC) Report for the National Assessment of Potential Consequences of Climate Variability and Change for the United States (Gornitz, 2001; Jacob, 2001; Rosenzweig & Solecki, 2001; Gornitz, Couch, & Hartig, 2002). The region can be considered as an example of a megacity of global importance in international business, finance, trade, culture, education, and diplomacy. The combined New York City/MEC region's role as a megacity is closely linked to its highly developed infrastructure, particularly an efficient and reliable public transportation system. Economic activity, public safety and health depend on growth and modernization of its complex infrastructure. Appropriate responses or adaptations to changing circumstances, including climate change, are essential in maintaining this region's global position.

The greater New York City Metropolitan East Coast area (MEC) encompasses an area of 33,670 km^2, and 22 million inhabitants of which around 8 million reside in New York City

Managing Coastal Vulnerability

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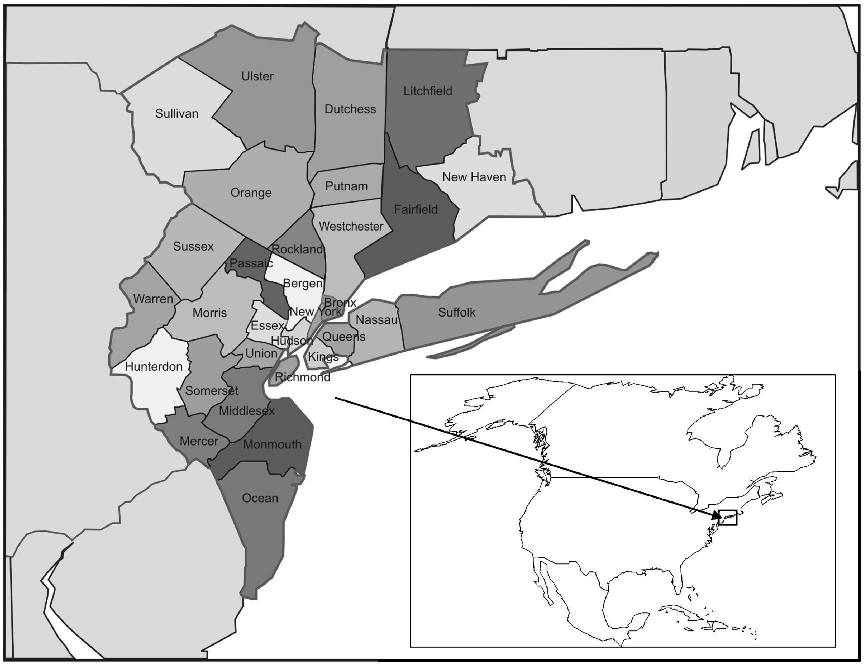

Figure 9.1: Map of Metropolitan East Coast Study Region with insert location. Thirty-one counties are indicated by name; 14 are located in the State of New York (five of which constitute New York City), 14 in New Jersey and three in Connecticut. For details see text.

proper. The definition of the MEC region adopted here is based on work-related commuter patterns moving a large work force to and from the central business district, largely in Manhattan, New York City. The so-defined MEC region (Figure 9.1) consists of 31 counties in three states (New York, NY; New Jersey, NJ and Connecticut, CT). Fourteen counties are located in NY State, five of which constitute New York City, 14 in New Jersey, and three in Connecticut.

With over 2000 km of shoreline, the region's development has historically been closely linked to the sea. Over 2000 bridges and tunnels exist in New York City alone, and many of the larger bridges connect the four (out of five) New York City island boroughs with each other and the mainland. High-density commercial and residential development is rapidly replacing abandoned factories and piers along the waterfront in metropolitan New York and New Jersey, as is happening in many other coastal cities that have moved from a manufacturing to a service industry-based economy. Mid-town and Lower Manhattan are two of the world's major financial centers. Plans are underway for the redevelopment of the (flood prone) World Trade Center site in Lower Manhattan, and of the Brooklyn waterfront, long home to the former Brooklyn Naval Shipyards. New vacation and year-round houses are under construction on barrier island dunes on Long Island, NY, and the northern New Jersey shore. Beaches and coastal wetlands provide recreational opportunities for urban populations and critical habitat for wildlife and fisheries. These littoral environments are caught between the twin pressures of development and increasing coastal hazards.

The south shore of Long Island is flanked by a string of barrier islands and beaches that developed after the end of the last ice age, as glacial sands and gravel were eroded and deposited into ridges and shoals offshore. The present barrier islands are only a few thousand years old, while the ancestral islands lay lower and seaward of their present positions. Most of the southern Long Island shoreline has been eroding over the last 150 years (Leatherman & Allan, 1985), associated with the historic SLR (Leatherman, Zhang, & Douglas, 2000; Zhang, Douglas, & Leatherman, 2004). Major erosion has continued or even accelerated *after* emplacement of jetties to stabilize several inlets, between the 1940s and 1960s, and construction of groynes near Westhampton, on eastern Long Island, in the late 1960s, which curtailed the westward longshore drift of sands. Similarly, the northern New Jersey coastline has tended to retreat since the 1830s, with increased rates of erosion at several localities following erection of "hard" structures. The United State Army Corps of Engineers has spent \$2.6 billion (1996-valuation) nationally and \$884 million within the Tri-State (New York, New Jersey, and Connecticut) region on beach nourishment costs starting in the late 1920s, with rapid cost accelerations since the 1950s. Over \$250 million was spent at just the six sites investigated for the MEC report (Gornitz et al., 2002).

The MEC region is affected by extra-tropical cyclones ("nor'easters") that occur largely between late November and March, and less frequently by tropical cyclones ("hurricanes") that typically strike between late July and October. A map of potential "worst-track" flooding scenarios for hurricanes of Saffir–Simpson (SS) scale 1–4 is shown for lower Manhattan (Figure 9.2).

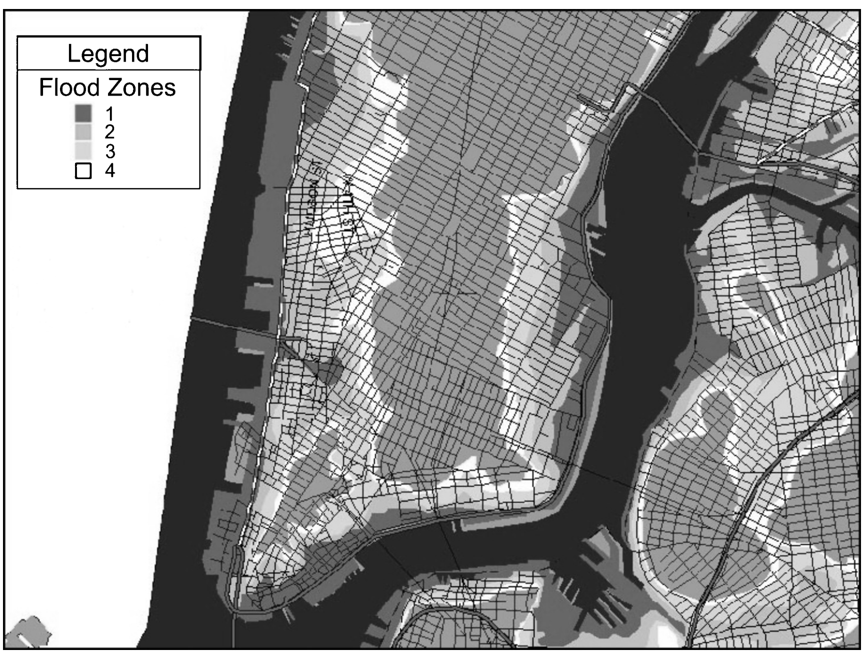

Figure 9.2: Expected zones of storm Surge flooding in lower Manhattan and parts of Brooklyn as a function of storm level on the Saffir–Simpson Scale (SS 1–4). For details see text.

Large tracts of lower Manhattan would be flooded, dependent on the storm's level. Figure 9. 2 shows the increase in flooded areas as a function of storm severity from SS = 1 to 4. Only the dark-shaded areas at the core of central and lower Manhattan are believed to be free currently from modeled flood hazards. Note that SS = 5 storms are currently thought to be unlikely in these mid-latitudes under current climate conditions. Shown flood zones assume sea level as of the year 2000. Flooding becomes more pervasive as SL rises. The "worst-track" storm surge for SS = 4 (lightest pattern) would be associated with a cresting surge height of about 10 m near the *Battery*, at the southern tip of Manhattan, and diminishes in amplitude upstream (northward). Note that for worst-track storms of SS = 3 and higher, lower Manhattan would be split into two islands in the vicinity of Canal Street, and would isolate the lower Manhattan "Financial District" (Wall Street, New York Stock Exchange, etc.). Such storm scenarios would require large lead times (at least 8 h) to achieve safe evacuation of the large office work force, especially since subway and vehicular tunnels are likely to become flooded, and major bridges may have to be closed because of high winds hours before the eye of the storm passes. The destructive potential of hurricanes arises from the combined effects of high winds (>120 km/h), heavy rainfall, and coastal flooding due to storm surge and waves. The flood height is magnified if the surge coincides with high tide. Although wind speeds of nor'easters are lower than those of hurricanes, they are capable of causing significant damage because duration is normally longer. The longer storm surge duration (days vs. hours during generally faster moving hurricanes) allows flooding to penetrate farther inland, and thus may cover a broader areal extent. The nor'easter of December 1992 produced some of the worst flooding in the New York City metropolitan area in 40 years, resulting in an almost complete shutdown of the regional transportation system and evacuation of many seaside communities. This storm revealed the vulnerability of the regional transportation system to weather-related disruptions. Most area rail and tunnel entrance points as well as the three major airports lie at elevations of 3 m or less above the locally still used reference mean sea-level datum of 1929 (U.S. ACOE/FEMA/NWS, 1995; U.S. Jacob, 2001). Flood levels of only 0.3–0.6 m above those produced during this storm could have led to even more severe flooding and to loss of life.

Neither Atlantic basin hurricanes nor extra-tropical cyclones show as yet any proven long-term trends in frequency, strength or spatial patterns in response to climate change. However, they do exhibit considerable inter-decadal variability. In particular, hurricanes may be entering again a more active period (Elsner, Jagger, & Niu, 2000; Zhang, Douglas, & Leatherman, 2000; Goldenberg, Landsea, Mestas Nuñez, & Gray, 2001) during the first two decades in the 21st century. Regardless, flooding due to coastal storms is likely to become more commonplace with rising sea levels, as the surge height will be superimposed on the higher ocean level.

We now review the vulnerability of the New York City metropolitan region to SLR, based on the findings of the MEC report. We outline relevant information and research needs to develop or improve the framework for coherent adaptation and coastal management policies facing the effects of global warming, and in particular rising sea levels.

Vulnerability of the New York City Metropolitan Area to Sea-Level Rise

Impacts of rising sea levels for selected localities within the MEC area were investigated. A suite of five plausible scenarios was used (Figure 9.3), based on extrapolation of historic

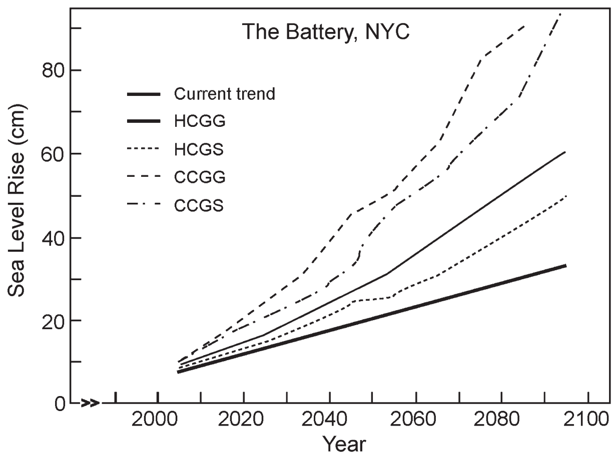

Figure 9.3: Five models of projected sea-level rise for the Battery at the southern tip of Manhattan, New York City. The models and abbreviations are explained in the text.

sea-level trends from tide gauge data and projections from the two global climate models (United Kingdom Hadley Centre, HC; Canadian Centre for Climate Modelling and Analysis, CC). In Figure 9.3, the models generated by the two centers (HC and CC), come each in two versions marked as GG and GS. GG stands for models that only considered the warming effects from green house gases, while GS stands for a modification of the GG models by considering in addition the slight cooling effect of sulfate aerosols in the atmosphere due to reflection and scattering of solar radiation. Note that the four models shown and the extrapolation of the historic SLR trend curve all include the local isostatic subsidence (Peltier, 2001).

The five SLR curves in Figure 9.3 use as a zero-baseline the averaged mean sea level for the period 1961–1990.

The SLR scenarios were coupled with U.S. Army Corps of Engineers surge (WES Implicit Flooding Model) and beach nourishment models (SBEACH; Bruun rule) (Gornitz et al., 2002). Storm surge probabilities were calculated at high tide for combined effects of hurricanes and nor'easters, assuming *no change* in storm frequency due to climate change, and *excluding* wave effects, both of which would worsen the flooding scenarios.

Mean global sea level has been increasing by 1–2 mm/yr for the last 150 years (Houghton et al., 2001), with 1.8 mm/yr a "best estimate" for the last 50 years (Church, White, Coleman, Lambeck, & Mitrovica, 2004). In the MEC region, observed 20th century rates of relative SLR range between 2 and 4 mm/yr, with an average value of 2.7 mm/yr for New York City (NOAA/NOS, 2005) since the 1850s, and a 10% higher mean rate for just the 20th century. Regional sea-level trends are somewhat higher than the global mean because of coastal subsidence in response to glacial isostatic readjustments (Peltier, 2001). By the 2080s, regional sea levels could climb by 0.24–1.08 m (Figure 9.3) above late 1980 levels, i.e. over a period of 100 years. More importantly, flood heights for the 100-year coastal storm could attain 3.2–4.2 m above the 1929 reference datum. Currently, the 100-year flood height above the same reference datum for New York City is 2.96 m — very close to the area shaded in gray in Figure 9.4.

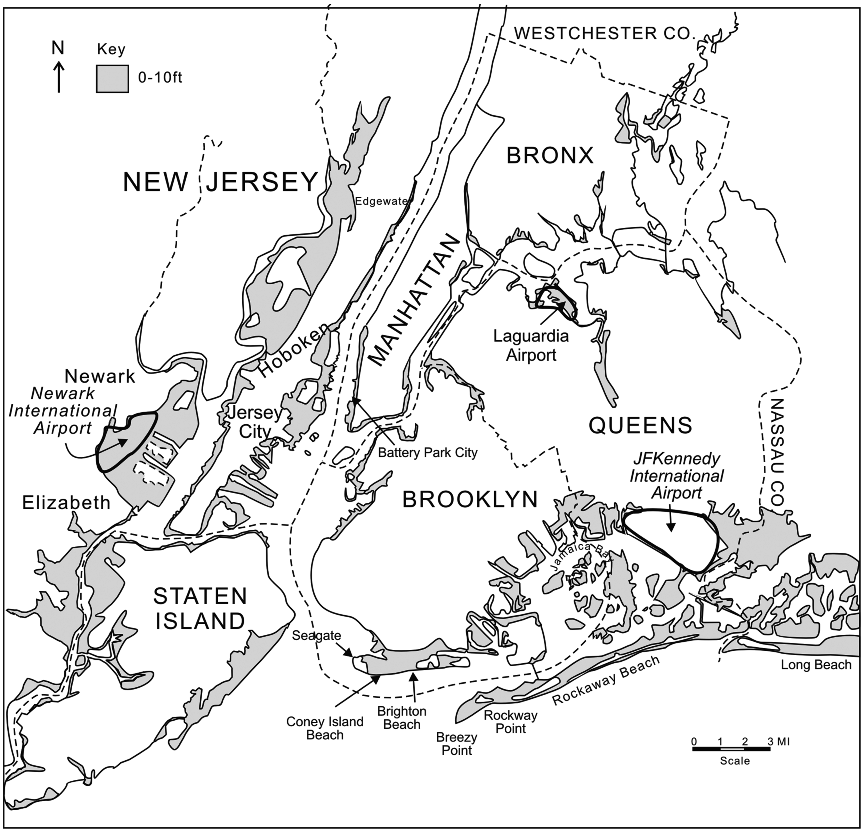

Figure 9.4: Map of the central portion of the MEC study area. Gray shading shows the areas at elevations below 3 m (10 ft to be exact) above the present mean sea level.

The zone within about 3 m above current sea level depicted in Figure 9.4 measures on the order of 300 km^2. This represents more than 10% of the total shown land area, and encompasses portions of lower Manhattan (New York County), coastal areas of Brooklyn (Kings County), Queens, Staten Island (Richmond County), Nassau County, NY, and the New Jersey Meadowlands (mostly in Bergen County, NJ, see Figure 9.1). Owing to SLR these areas could experience a marked increase in flooding frequency. For instance, the recurrence interval of the 100-year storm flood could shorten to as little as 4–60 years (Figure 9.5). The tidal wetlands of Jamaica Bay between Brooklyn (Kings County) and Queens, which provide prime habitat for migratory birds, already face serious losses and could disappear altogether with rising sea levels (Hartig, Gornitz, Kolker, Mushacke, & Fallon, 2002). Beach erosion rates could increase by 4–10 times over present rates (Gornitz et al., 2002). This would necessitate up to 26% additional sand replacement by volume (and associated costs) on beaches, due to SLR alone. Economic losses from storm flooding and inundation is expected to triple (see below).

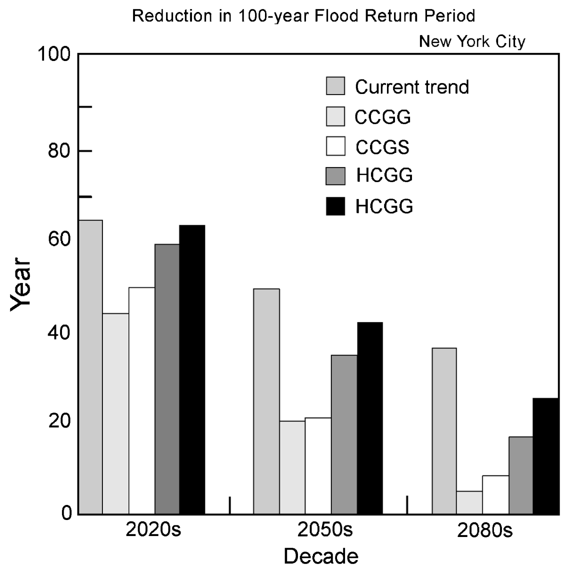

Figure 9.5: Reduction in the 100-year recurrence period for three future decades and the five sea-level rise models as shown in Figure 9.3.

Many elements of the regional transportation system, other essential infrastructure, such as sewage and wastewater treatment plants, as well as commercial and residential property lie at elevations of 2–6 m above present sea level — well within the range of projected surges for tropical and extra-tropical cyclones (Jacob, 2001). Even the seemingly modest increase in sea level of up to 1 m by the end of the century would raise the frequency of coastal storm surges and related flooding by factors of 2–10, with an average of around 3. This would place many public facilities, and especially low-lying critical elevations of many transportation systems, at ever more frequent flood hazards (Figure 9.6).

The rate of losses incurred by the entire region from storms and coastal floods would increase correspondingly with the increased frequency of flood hazards (Table 9.1).

Anticipated annualized average losses due to these floods, on the order of $1 billion/year, appear to be relatively small compared to the annual $1 trillion (2000) regional economy. But in reality major losses do not occur in regular annual increments. Instead, they result largely from less frequent, high-magnitude, extreme events. Extreme storm losses can be expected in this region to exceed $100–200 billion in some cases. During the recovery period, the regional economy could show signs of strain, local businesses could close, and insurers would be stretched to the limit. The approximate $100 billion loss to the regional economy in the aftermath of the September 11, 2001 terrorist attacks on New York City are expected to adversely effect the MEC economy for at least a decade. Nearly half of the 2001 losses appear to be insured losses. The insurance industry was ill prepared and severely strained after losses associated with hurricane Andrew that hit Florida in 1992 and caused total losses of about $20 billion of which less than half were insured losses. The 2004 hurricane season with four major hurricanes originating in the Atlantic that hit

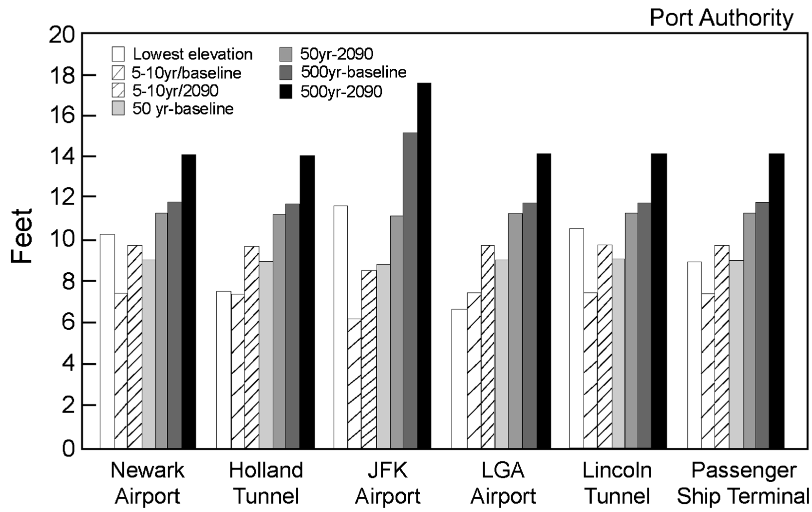

Figure 9.6: Current lowest critical elevations of facilities operated by the Port Authority of New York and New Jersey vs. changing storm elevations at these locations for surge recurrence periods of 10, 50 and 500 years between 2000 (baseline) and the 2090s. See text for details. *Note*: 10 ft equal approximately 3 m.

the U.S. coasts produced *insured* losses currently estimated to exceed \$20 billion, despite the fact that none of the hurricanes had landfalls near a major city. Especially New Orleans (a large portion of which lies *below* sea level behind levees) escaped narrowly the path of the 2004 hurricane *Ivan*, but was squarely hit by Katrina in 2005. Risk consultants to the insurance industry advised that the 2004 losses from hurricanes were not unusual and that insurers should be prepared to deal with similar or even higher losses on a regular basis (Anonymous, 2004). The same source states that historically the year 2004 is one of 8 years in the last century that had hurricane-related insurance losses exceeding \$20 billion, when adjusted to 2004 valuations. With climate change and SLR and with expanded coastal development, these losses are expected only to rise. The forecasts materialized promptly in 2005 with combined economic losses from Katrina and Rita estimated \$140 billion (\$65 billion insured).

Coastal Risk Management and Adaptation Issues

Science and Technical Needs

Coastal managers and other public officials need accurate, reliable, realistic information about current and future climate, as well as socioeconomic trends upon which to base their decisions. While the MEC report represents an important step forward in assessing climate change impacts in a major urban area, a number of issues were identified that require further

Table 9.1: Estimates of losses (in 2000-US$) in the MEC region for storms with shown surge heights.

Equivalent Saffir-Simpson category[a]	**Surge height**[b]		**Surge recurrence period (years) in**		**Estimated total losses (billon $)**	**Annualized losses (million $/yr)**	
	(ft)	**(m)**	**2000**	**2100**		**2000**	**2100**
Extratopical storm	8	2.4	20	6	1	50	170
1	10	3.1	50	15	5	100	330
2	11	3.4	100	30	10	100	300
3	13	4.0	500	150	50	100	300
3–4	14	4.3	1000	300	100	100	300
4	16	4.9	2500	800	>250	100	300
All storm categories combined						500	1500

Note: The surge recurrence periods shorten from 2000 to 2100 by an average factor of 3 due to SLR alone, and annualized losses roughly triple. The exposed asset values and storm frequencies are assumed to remain at the 2000 levels. Actual increase in assets and storm frequency would further increase losses. For details see text.

[a]Use only the year 2000 recurrence period for this first column, since the study assumed the frequency of storms would remain the same, and only the surge frequency for same surge height would shorten due to SLR.

[b]Surge height above the National Geodetic Vertical Datum (NGVD) of 1929, which then represented approximately local mean sea level.

investigation, because of limitations in data availability, uncertainties in the models used, or incomplete understanding of basic physical and socioeconomic processes. Reducing uncertainties associated with future SLR requires better knowledge of heat penetration into the oceans (e.g. Levitus et al., 2001), the resulting thermal expansion (Cabanes, Cazanave, & Le Provost, 2001), rates of mountain glacier melting (Dyurgerov & Meier, 2000), and the likely contributions of the Greenland and Antarctic ice sheets (Gregory, Huybrechts, & Raper 2004; Thomas et al., 2004). Furthermore, we need to be able to anticipate changes in tropical and extra-tropical storm frequencies and intensities, and how such changes will affect coastal flooding and beach erosion. New physically based models need to be developed to relate the shoreline's response to SLR. Existing models are often based on empirical relationships, which in turn are based on oversimplifications of incompletely understood complex physical processes (Thieler, Pilkey Jr, Young, Bush, & Chai, 2000). Other important effects of SLR not fully understood in their consequences are upstream migration of the Hudson River salt front and its effects on the Chelsea Pump station, an emergency source of drinking water for New York City during periods of drought. The pump station is located about 90 km upstream from New York City. Related issues are the infiltration of saltwater into already stressed Long Island aquifers, and the effects of salinity changes on the estuarine ecology.

Other types of information needed for improved impact assessment include: more detailed topographic data down to 10-cm resolution over land, and 1-cm resolution near sea level; more detailed data on recent and historic storm damages; accurate inventories of major infrastructure components, their fragility with respect to storm surge, flooding, and wind hazards; their monetary value; and finally, data management and improved storm surge damage modeling capabilities such as that provided by the HAZUS-MH-MR1 tool (FEMA, 2005). The HAZUS multi-hazard (MH) loss assessment tool uses *Geographical Information Systems* (GIS) and currently allows us to quantify damage levels, physical, financial and economic losses, and other impacts from three types of hazards: wind, (riverine and coastal) flooding, and earthquakes. HAZUS can be applied to individual deterministic scenario events, or probabilistically. The latter option allows obtaining annualized losses. HAZUS and similar risk and loss assessment tools have been used for about a decade by the insurance industry for portfolio risk management, and by federal, state, and local governments for emergency planning and disaster-response management. These tools undergo continuous refinements and require time-consuming efforts to keep pertinent data bases updated on hazard assessments, changing asset inventories, and asset fragilities/vulnerabilities to the various hazards.

The stated scientific and technical needs require concerted and sustained investments into financial and personnel resources. The academic/professional research communities, the private business sector, and the various levels of government must share commitments. It requires especially close cooperation and partnerships by many stakeholders that operate large infrastructure/utility systems, whether privately or publicly owned and managed. Their databases and technical know-how are invaluable to assessing and managing the coastal risks and vulnerabilities realistically and effectively. The MEC study experienced mixed results, with both successes and failures to achieve these partnerships and establish a sustained network of active and knowledgeable professionals that could advance the scientific and technical base for assessing and managing the coastal vulnerabilities in the region.

Responses to Coastal Hazards

A number of local, state, federal and private agencies are responsible for responses to natural disasters. The National Weather Service (NWS) of NOAA routinely tracks storms by satellite and furnishes hurricane or storm flood warnings. The NWS works closely with the New York/New Jersey/Connecticut State Emergency Management agencies and the New York City Office of Emergency Management to assess the situation at a local level. These state or city agencies then decide whether or not to declare a storm emergency and whether to recommend closure of government offices, schools, and private businesses. If necessary, evacuation of low-lying areas and beaches via prescribed evacuation routes to emergency shelters is ordered. The Federal Emergency Management Agency (FEMA) provides financial aid for reconstruction efforts. FEMA's National Flood Insurance Program (NFIP) underwrites flood insurance to communities that adopt measures to reduce future flood risks in hazardous areas (FEMA, 1997). U.S. Congress passed Public Law 106–390, the "Disaster Mitigation Act of 2000" to strengthen FEMA assistance to communities for mitigation measures, especially for properties in flood zones where past repeated losses had occurred, while limiting *future* disaster assistance if after *repeated* flood disasters, mitigation measures have not been undertaken. NFIP also specifies designation of erosion zones and setbacks or buffer zones for highly vulnerable coastal areas. The U.S. Army Corps of Engineers builds and manages dams and levees to minimize flood damage. They also undertake beach "nourishment" and some tidal marsh restoration projects. Although the Army Corps factors *historic* SLR rates into their projections of sand volumes needed for beach nourishment, they so far have not considered the possibility of future *accelerated* SLR. Despite these general measures, often on the federal level, development pressures on the local level continue to place even new assets in flood prone areas, or in areas that will become flood prone in the future due to rising sea level.

Organizations and institutions are more likely to react to rapid-onset hazards lasting several hours or days (e.g. flooding from storm surges), rather than to slow-onset hazards that develop over longer time periods (e.g. coastal erosion and SLR). Measures to reduce vulnerability to future coastal hazards, such as SLR, should build upon already-existing programs and institutional mechanisms. For example, SLR projections should be incorporated into the design, siting, and construction of new or updated facilities. An example for an *obstacle* to such forward-thinking, preventive measures is NFIP's *flood insurance rate mapping* (FIRM) program. FIRM flood-zone maps are used for land use planning and construction regulations by many local jurisdictions. But FIRM maps do not yet recognize the *future* contributions in areal (and vertical) extent of flood zones due to any SLR, not to speak of future accelerated rates of SLR. Therefore, FIRM maps in coastal zones, even those currently produced under the current FIRM map modernization program costing in excess of U.S. $1 billion, will become outdated during just a few decades. Many new investments in or near the currently defined coastal flood zones (which ignore future SLR) will suffer ever-increasing losses. Other examples of missed or successful adaptation measures are provided below.

One adaptation option that does not protect the outer shores and barrier islands, but is intended to protect the New York–New Jersey Harbor estuary, has been recently proposed and would consists of three strategically placed storm surge barriers. This concept is in the earliest stages of scientific exploration (Bowman et al., 2004) of its technical and environmental implications. Therefore, its economic, cost/benefit and political feasibility and long-term environmental impacts are as yet entirely unknown. It would be a capital-intensive "structural" solution (meaning an engineered solution) that would provide *physical* defenses against the hazards from SLR and storm surges. To some extent it would therefore implicitly promulgate the otherwise unsustainable waterfront land-use and development policies of the past and present. This approach to adaptation would be in contrast to any "non-structural" solutions that would curtail waterfront development and require changes in land use and zoning regulations, perhaps even relocation or raising of structures and infrastructure systems near the present waterfront. The barrier solution would build on the experiences gained with similar storm surge protection systems built in the Netherlands, and across the Thames River near London. Preliminary hydrological modeling results are given by Bowman et al. (2004). It is too early to tell whether such structural approaches have any merit or chance of future realization, especially since they only protect assets and people in the inner harbor, but not those directly exposed along the Atlantic coast or the Long Island Sound. The public is only gradually beginning to confront implications from SLR and other effects of climate change for the New York City metropolitan region. It is uncertain at this time whether the public process toward any expensive mitigation measures, whether structural or non-structural, can be politically advanced without the region first having to experience a catastrophic storm surge disaster. In the Netherlands and England the tragic 1953 North Sea storm floods triggered there the respective flood protection engineering projects. Currently the U.S. is in a lively discussion (Mileti, 1999) whether non-structural (land use, zoning, and code) measures are better suited than structural (dam, levee, and barrier) measures to provide sustainable protection for communities. The focus of the discussion is on economically sustainable protection, i.e. short-term vs. the long-term measures, especially since there are no well-known upper limits for SLR when projecting many centuries ahead. Sustainability means we should not lock urban development and current expensive long-term investments of infrastructure into a pattern that ultimately will need to be abandoned. The costs of risks and risk mitigation should be balanced equitably between current and future generations.

Institutional Structures

A large and varied group of institutions and governing bodies throughout the MEC region is involved in tasks relating to coastal management (Zimmerman, 2001). Some key organizations and agencies and their functions are summarized in Table 9.2 (see also Appendix Decision-Making 1 and 2, in Rosenzweig & Solecki, 2001). Fragmentation of jurisdictions among federal, state, and local governments and inter-agency communication shortcomings hinder development of a coherent, comprehensive regional coastal management plan. Authority and responsibilities are highly specialized by function and territory. On the other hand, new plans for regional capital improvements can be designed to include measures that will reduce vulnerability to the adverse effects of SLR. Wherever plans are underway for upgrading or constructing new roadways, airport runways, or wastewater treatment plants which may already include flood protection, these need to be planned or modified to take projected SLR into consideration. The extent and effectiveness of such adaptive measures will depend on building awareness of these issues among decision makers, fostering processes of interagency interaction and collaboration, and developing common standards (Zimmerman, 2001).

A distinctive feature of the MEC project was the participation of key stakeholders throughout the assessment process. Stakeholders consisted of institutions or groups "whose activities are and will be impacted by present and future climate variability and change, and thus have a stake in being involved in research of potential climate impacts". Groups included federal, state, and local government agencies, as well as several universities (Table 9.3). Stakeholder partners, such as the U.S. Army Corps of Engineers, provided critical data, model outputs, as well as offering advice and feedback.

The Port Authority of New York and New Jersey (PANYNJ) is a major regional owner/operator of infrastructure facilities (ports, airports, bus terminals, major trans-Hudson bridges and tunnels, and — until 2001 — the World Trade Center (WTC). PANYNJ was also a very active stakeholder and participant in the MEC study. It had already undertaken several mitigation measures at its facilities, although some of these measures will be effective only for a limited time and may eventually be overtaken by SLR, and thus may need further modifications. It has built, for instance, a dike and levee

Table 9.2: Selected key institutions in the New York City Metropolitan area with a stake in coastal zone management.

Organization	Jurisdiction	Function/Authority
NYS DOS (Department of State) Div. Coastal Resources	NY	Coastal zone management planning.
NJ Office of State Planning	NJ	Coastal zone planning, land use
CT Department of Environmental Protection	CT	Issues permits to regulate development: coastal management act, tidal wetlands, structures, dredging and fill
NJ Department of Environmental Protection	NJ	Waterfront Development Law, Coastal Area Facility Review Act, Wetlands Act of 1970, Flood Hazard Area Control Act, and the Tidelands Act
NY State Department of Environmental Conservation	NY	Environmental Conservation Law Permits-Protection of Waters, Tidal Wetlands, State Water Quality Certification
U.S. Army Corps of Engineers-NY District	NY and NJ	Dredge and fill permits, shipping channels (Rivers and Harbors Act), wetlands permits (Clean Water Act), beach nourishment
Port Authority of New York and New Jersey	NY and NJ	Develops, operates, maintains Port Authority bridges, tunnels, PATH trains, port facilities, ferries, and airports
New York City Department of Transportation	NYC	Operates and maintains city-owned roads and bridges
New York State Department of Transportation	NY	Operates and maintains state-owned roads and bridges
Metropolitan Transportation Authority	Mainly NYC	Owns, manages, operates, maintains New York City subway system
New Jersey Transit	NJ–NY	Owns, manages, operates, maintains buses and trains linking northeast New Jersey with New York City
NJ Office of State Planning	NJ	Infrastructure needs Assessment 2000–2020
NYC Department of Environmental Protection	NYC, upstate	Owns, manages, operates, maintains wastewater treatment plants, sewers, and associated equipment (pumps, regulators, etc.)

(*Continued*)

Table 9.2: (*Continued*)

Organization	Jurisdiction	Function/Authority
NYC Office of Emergency Management	NYC	Responds to natural and man-made disasters
NYS Emergency Management Office	NYS	Responds to natural and man-made disasters
NJ Office of Emergency Management	NJ	Responds to natural and man-made disasters
CT Office of Emergency Management	CT	Responds to natural and man-made disasters
FEMA, Region II	NYS and NJ	Responds to natural and man-made disasters; National Flood Insurance Program (NFIP).
FEMA, Region I	CT	Responds to natural and man-made disasters; National Flood Insurance Program (NFIP)

Source: Zimmerman (2001).

Table 9.3: Stakeholder partners in the MEC project/coastal zone study.

Name	Organization
Stephen Couch	U.S. Army Corps of Engineers, New York District
Bruce Swiren	Federal Emergency Management Agency, Region II
Christopher Zeppie	Port Authority of New York and New Jersey
John T. Tanacredi[a]	National Park Service, Gateway National Recreation Area
Frederick Mushacke	New York State Department of Environmental Conservation
David Fallon[b]	New York State Department of Environmental Conservation

[a]Now at Department of Marine Sciences, Dowling College.
[b]Retired.

system around the LaGuardia Airport, one of the three major regional airports. Before the protective measure, LaGuardia Airport had been repeatedly flooded especially by nor'easter storms, as early as the 1950s. The severe nor'easter storm in 1992 flooded the PATH tunnel under the Hudson River, used by commuter trains between Hoboken (New Jersey), and Manhattan (New York). PANYNJ built floodgates at the tunnel entrance and provided other flood protection on the NJ side from which the floodwaters had entered. The flood put the PATH trains out of operation for 10 days. One of the first construction projects after the terrorist attacks on the World Trade Center on September 11, 2001, was for PANYNJ to raise at the WTC site the perimeter slurry wall to an elevation of 1 ft (about 0.3 m) above the FEMA-established 100-year flood elevation. When hurricane *Isabel* threatened the U.S. east coast in 2003, resident engineers at the WTC reconstruction site ensured that material and equipment was readily at hand to seal temporary construction entry ways through the slurry wall, should this become necessary. It turned out it was not needed. But given the rate of SLR, the voluntary 1-ft extra margin of the slurry wall above the FEMA/NFIP-set levels for the 100-year flood elevation will be erased probably before the year 2050. This important downtown Manhattan redevelopment and reconstruction project could set an example for forward-looking preventive measures that anticipate the projected, accelerated SLR and the resulting increased storm surge flood hazards.

Conclusions

The Metropolitan East Coast (MEC) vulnerability assessment and report (Rosenzweig & Solecki, 2001) for the *National Assessment of Potential Consequences of Climate Variability and Change for the United States* is an important, albeit small step toward facing the increasing storm surge flood hazards and risks for this highly urbanized and increasingly vulnerable region. Key findings include a potential regional rise in sea level between about 0.24 and 1.08 m by the year 2100, a marked increase in the storm flood recurrence frequency (i.e. shortening of recurrence periods from 100-years to as little as 4 years for the fastest SLR scenario), and 4–10 times greater beach erosion by the 2080s, as compared to late 20th century rates.

Since many elements of the regional transportation and other infrastructure and built assets lie at elevations of 2–6 m above present sea level they are exposed to current and projected future coastal storm surge risks from tropical and extra-tropical cyclones. Major and wide-spread damage occurring during high-impact, low-frequency storm surges can measure in the tens of billions, and for the most severe storm scenarios could well exceed U.S. $100–200 billion. Such losses are expected to have significant repercussions for the regional economy. The economic effects may last a decade or more. The rate of storm-surge risk (annualized long-term average of future losses) is expected on average to increase three-fold during the current century, just from SLR alone, not counting that new vulnerable assets may be added in hazardous locations, and that climate change may increase the storm intensities and frequencies.

To protect the current and future assets of the metropolitan New York City region, and to enhance its reputation as a safe and attractive global center for business, trade, culture education and diplomacy, a coherent long-term plan for coastal risk management and adaptation needs to be implemented. The singular and limited efforts of a few institutions to address the coastal risks and adaptation options are inadequate for the task facing the region. Evacuation planning is reasonably well advanced but largely untested for truly severe scenarios. Turning water front property and former piers, for example on the west-side of Manhattan facing the Hudson River into park and recreational facilities, are encouraging protective measures. But these positive measures do not address the greatest risks, especially for the very vulnerable low-lying infrastructure virtually unmitigated. The institutional authority and responsibility is often narrowly defined, fragmented and hampered by a historically based, divided, yet often overlapping set of jurisdictions and public functions. This institutional disposition tends to foster bureaucracies that are more interested to protect their own survival and economic basis than that of the common good and public safety. The periodically low interest at various levels of the federal government in the causes and effects of climate change does not release the local and state governments from their responsibilities to act on behalf of the long-term safety interests of the regional and local public. Public safety is largely a state and local function in the U.S.

Perhaps, the scientific and engineering professional communities will need to define the current and increasing risks more clearly, convey them in unison and hence more forcefully, without shying away from pointing out the inherent uncertainties. But inherent uncertainties cannot be used as an excuse by decision makers for public inaction especially when mean trends and observable facts and analyses are on average clearly pointing to ever-increasing predictable risks.

A state-governor-appointed task force at least involving New York and New Jersey (but also perhaps Connecticut) may be a much-needed option, with proper authority and input especially from the New York City government, to develop overarching regional plans and priorities. In addition, New York City needs its own long-term master plan to address its internal coastal and waterfront storm-surge risks. But this City effort needs full integration with the regional state plans. Without the political will and vision, supported by sound science and engineering, the region will face ever-increasing coastal risks, and eventually inevitable (yet partly avoidable) catastrophic losses.

A congressionally mandated, federally funded new study to be released soon (NIBS-MMC, 2005) assesses how beneficial the return from every dollar invested in mitigation of natural hazards is, based on U.S. (FEMA) experience over the last few decades. The study reports a wide range of benefit-to-cost ratios depending on hazard, project type, location, and mitigation process. Benefit–cost ratios for virtually all assessed mitigation projects was found to be above 1, with many clustering around a 3-dollar return for every 1-dollar investment of risk mitigation, and some substantially higher returns. One wonders when decision makers in the communities, and the public at large, will catch up with sound business practice as the basis for managing coastal risks and adaptation to a dynamically changing environment. The ultimate goal of preventive and adaptive actions is to save lives and make human activity sustainable. This truism becomes especially important for regions, like the MEC, where populations and assets are concentrated in large vulnerable coastal cities.

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